MUCOOL - LH2 Absorber window - Pressure test
Measurement of the strain

1 Goal

This memorandum describes the techniques considered and the measurements performed with the strain gages installed on the LH2 absorber window.
We use the strain gages in order to measure the behavior of the absorber window while a water pressure is applied to the concave side of the absorber window. In addition to the measurement of the strain, we will measure the deflection of the window with the photogrammetry technique. Both deflection and strain measurements will be compared to the finite element analysis results that were performed for the R15 cm absorber window - 130 micron thick.
The strain gages were also installed on aluminum specimen simulating the window thickness and finishing. This first test permits us to check the precision of our measurement.

2 Definitions

2.1 Material properties

Aluminum 6061 T6, was chosen as the absorber window material (low Z). The Young's modulus of this material is equivalent to 68 GPa and was used in the FEA. The poisson ratio is 0.3.

2.2 Strain

The strain, ε, is defined by the deformation per unit length, measured when an uniaxial force is applied to this body.
The strain is dimensionless ratio and of the order of the 10^{-6} therefore often expressed as $\mu\varepsilon$.

$$\boxed{\varepsilon = \Delta L/L}$$

2.3 Stress-strain relationship and Young's modulus

The relationship between the strain, ε, and stress, σ, permits us to introduce the Young's modulus (or modulus of elasticity), which is one of the main characteristic of the material.

$$\boxed{\sigma = \varepsilon E}$$

3 Choice of the strain gages

3.1 Composition

The strain gages that we have chosen are bonded resistance strain gage types.
The gages are chosen regarding the following parameters:

- thickness (as thin as possible to minimize the influence of the gage itself in the measurement)
- strain range (we mainly focus on the elastic range of the Aluminum)
- filament material (the most stable material is requested)

The best fitted products are 1 mil thick (backing film thickness). They are composed of constantan filament. Their strain range is ±5% (50,000 $\mu\varepsilon$).

The strain gages are provided and calibrated by micro-measurement Inc. Their types are:

Unidirectional type: EA- 03 - 250 BF - 350
Rosette type (3 gages): EA- 06 - 125 RD - 350

- Type "EA-" is an open-faced general purpose gage with tough, flexible polyimide backing. The "A" stands for a constantan alloy in self-temperature compensated form.
- "03"and "06" correspond to the self-temperature compensation, which would be useful for a test at cryogenic temperature.
- The active gage length has been selected to match the strain precision requested (125 or 250 mils).
- "BF" and "RF" stand for the grid geometry.
- "350 Ω" is the initial resistance of the gage.

3.2 Characteristic of the gage

3.2.1 Gage factor

The gage factor, GF, is the measurement of the resistance change with the strain. For each of the strain gage, the gage factor is equal to 2.08±1%.
The gage factor is defined by:

$$\boxed{\frac{\Delta R}{R} = \frac{\Delta L}{L} * GF}$$

Influence of the lead wire resistance. Since the circuit permits to register the voltage, the resistance of the lead has to be taken into account. A new gage factor is calculated as followed:

$$\boxed{GF" = GF * \frac{Rg}{Rg + Rl}}$$

With Rg and Rl the resistance of the gage and the lead, respectively.
If Rg = 350 Ω and Rl=0.5 Ω then GF" = 2.077

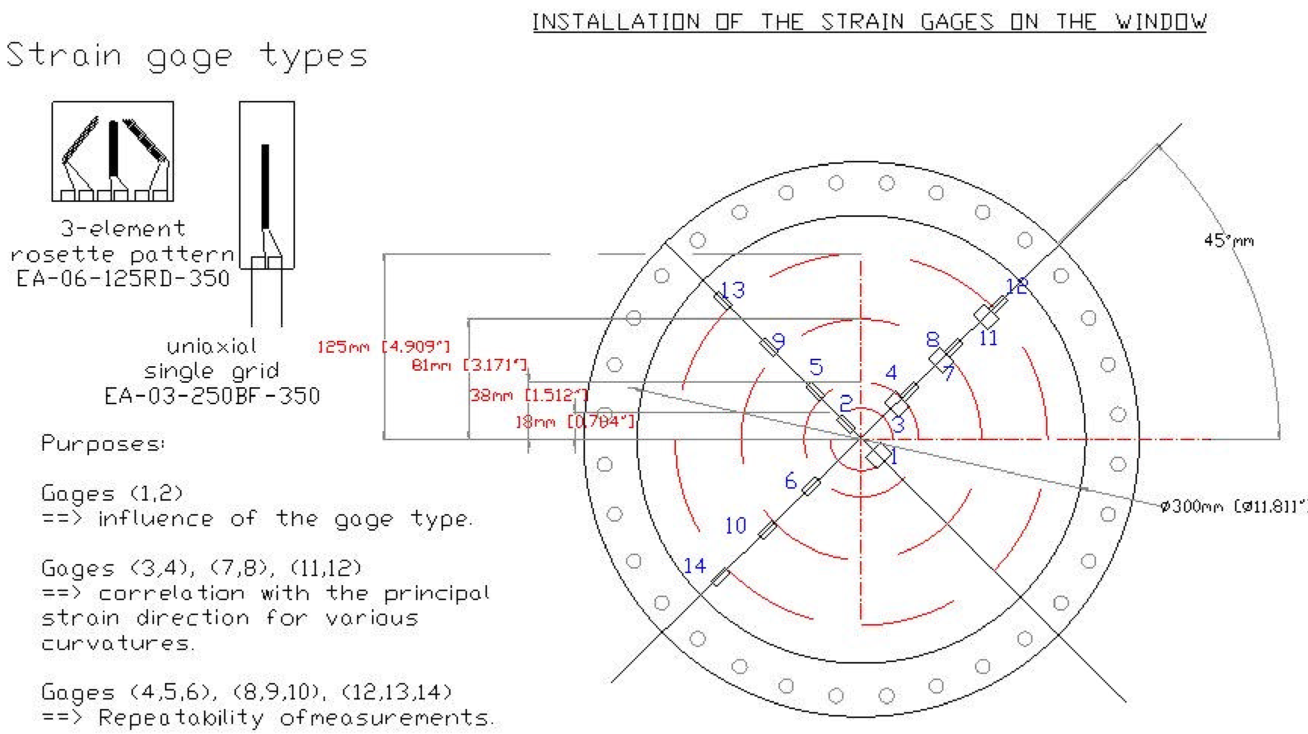
3.2.2 Temperature influence

For an operation at cryogenic temperature, we should correct the gage factor (see graph: variation of gage factor w/ temperature). In our current application, we will run at room temperature.

4 Installation of the strain gage

4.1 Bonding

The strain gages are bonded on the thin aluminum window. First we needed to reinforce the window since a pressure had to be applied on the gage during its installation. We used an adhesive ("M-Bond 200" from M-line catalogue at micro-measurement) and a catalyst.



4.2 Location

The gages are located regarding the following position:

5 Measurement principles

5.1 Reference gages

Reference gages are mainly use for cryogenic temperature application, but in our case, they permit us a more precise measurement of the strain. One reference gage is attributed to each of the active gages. The reference gage is installed with equivalent parameters then its corresponding active gage (gage resistance, wire resistance..).

5.2 Readout with resistance measurement

Four-wire strain measurement technique will permit us to determine the strain, ε, resulting from the pressure applied to the concave side of the window.
We can determine the strain, ε, by measuring the resistance.

$$\boxed{e = \frac{\frac{\Delta R}{R}}{GF}}$$

This technique was first applied for the tension test.

5.3 Readout with voltage measurement

The Wheatstone bridge circuit is used in order to improve the sensitivity of the strain measurement. If we consider the use of the reference gages, then we call it a 1/2 bridge.

The measurement of the ratio E (bridge excitation voltage) and Eo (bridge output voltage) in mV (Voltage/Gain) permit us to determine the strain. In the linear range of the gage we can express the strain, ε, as:
E=3.33V and Gain=500

$$\boxed{e = \left(\frac{Eo}{E}\right) * \frac{4}{GF"*10^{-3}}}$$

For strain larger than 1,000 microstrain, the error would be of the order of 1% if we would not take into account a non linearity term. Therefore the expression of the strain is:

$$\boxed{e = \left(\frac{Eo}{E}\right) * \frac{-4}{10^{-3} * GF"*(2*\frac{Eo}{E}*10^{-3} - 1)}}$$

6 Analysis of the measurements

The procedure summarizes the operation (see test procedure).
First step is to balance the Wheaststion bridge then to cycle to window three times up to 15 PSI (0.1 MPa) and back to zero. The voltage and/or resistance registered will be the initial value.
Then, the test will be performed up to the rupture of the window regarding the proposed scenario.
The pressure of water is incrementally increased and the measurement of the strain is performed in static condition. The strains are first estimated from the voltage measurement up to the 5B module limit, then from the resistance measurement till the rupture of the part (see chapter 5).

6.1 Principles

6.1.1 Stress - Strain

Once we have registered the voltage and/or resistance evolution for the given pressure. We can plot the behavior of the window and compare it with the FEA results. The position of the gages and the coord. system determination will allow this correlation.

6.1.2 Tension test - calibration of the strain measurement

In the case of the tension test, which defines the precision of the measurement, we analyzed the data by the following steps:
1 - plot. strain vs. load : the strain is determined by ΔR or ΔV.
2 - plot. pressure vs. load : stress equivalent to the force applied on the cross section area of the coupon (specimen)
3 - plot. strain vs. load : then we can determine the Young's modulus, which will be compared with the value from the literature. The variation from the theory value determine the precision of the measurement.

6.2 *Error evaluation*

6.2.1 Curvature - Principal strain

The curvature of the window imposes us to consider the radial and azimutal strain viewed by each gage. The azimutal strain is supposed to be negligible compared to the radial strain. Nevertheless we want to validate this assumption. For this reason, rosette type gages (three elements rosette pattern) are used in order to determine the principal strain. The location of all the other uniaxial strain gages will permit us to correlate the measurements of the rosette type and uniaxial gages. The repeatability of the measurement will be also taken into account.

6.2.2 Bonding

The three cycling of the gages with a low pressure will permit us to minimize the influence of the bonding between the gage and the aluminum.

6.2.3 DAQ

The ADC will focus and recording dynamic measurement and the Keithley DVM will provide precise measurements (6-1/2 digits).

More information available at http://tspc01.fnal.gov/darve/mu_cool/pressuretest/pressuretest.html